ICEsat-2 higher-level elevation products

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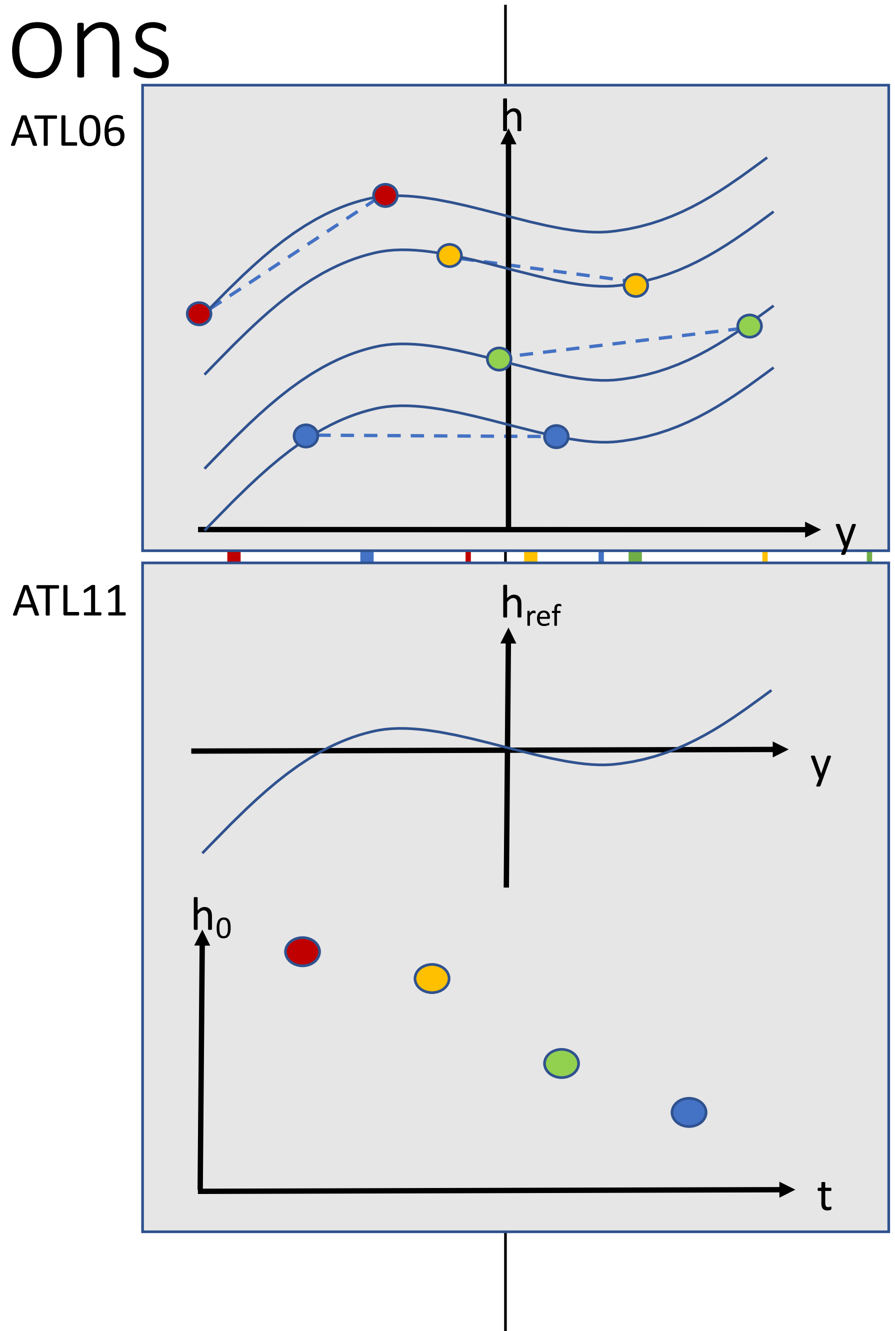
ATL11 and surface-height corrections

- ATL11 gives h(t) for a given point covered by repeat tracks
  - Uses consistency checks to cull blunders from the ATL06 record
  - Computes a local-topography correction to remove height variations due to small-scale surface slopes
  - **Gives values that can be directly differenced to give dh/dt**

- The product should be regenerated at the end of each mission year
  - Regenerating the product improves the estimate of the reference surface
  - Each generation will use all data available to date



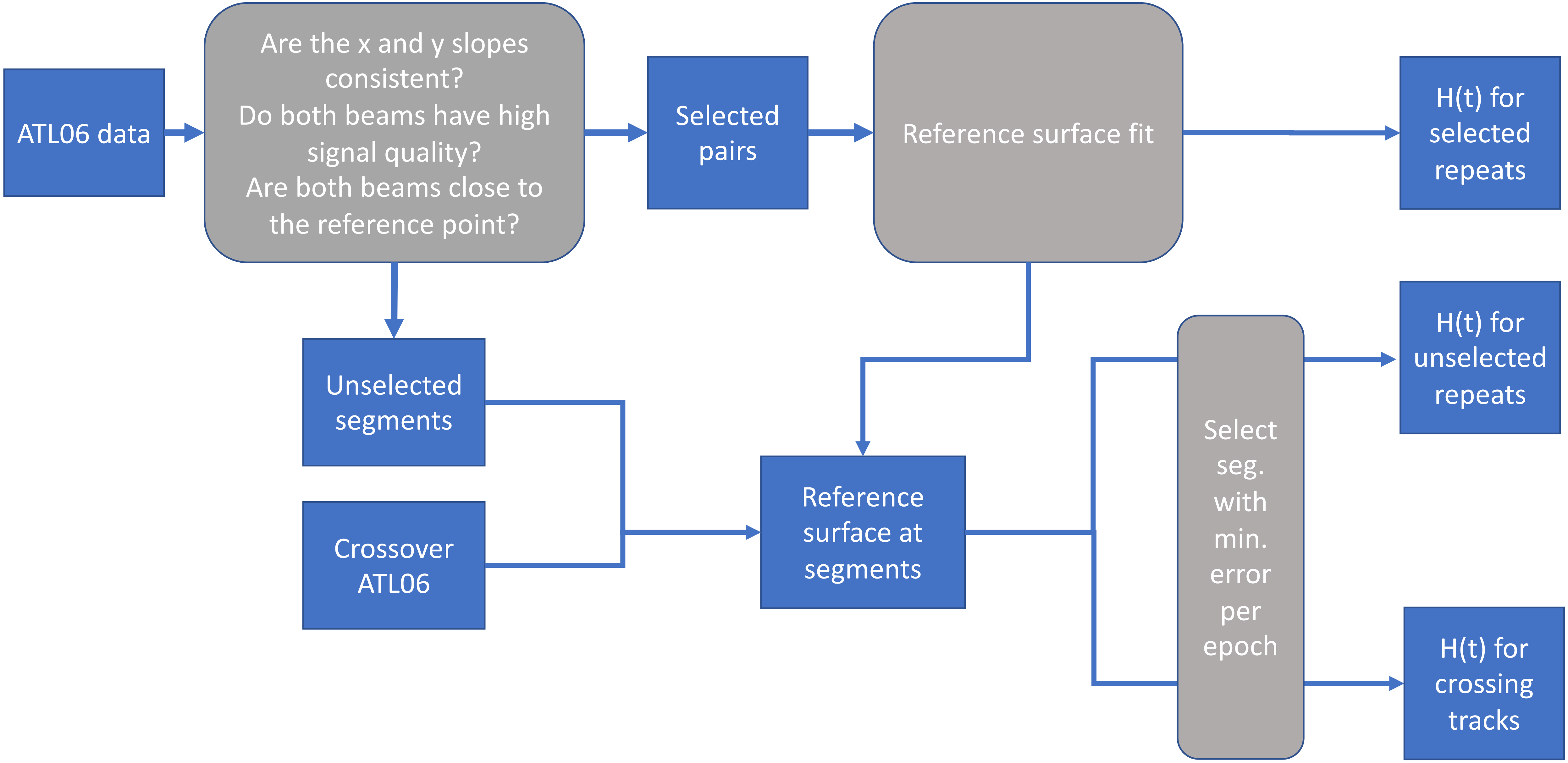
ATL11 data scheme

4 repeats/yr

1 reference pt/ 60 m

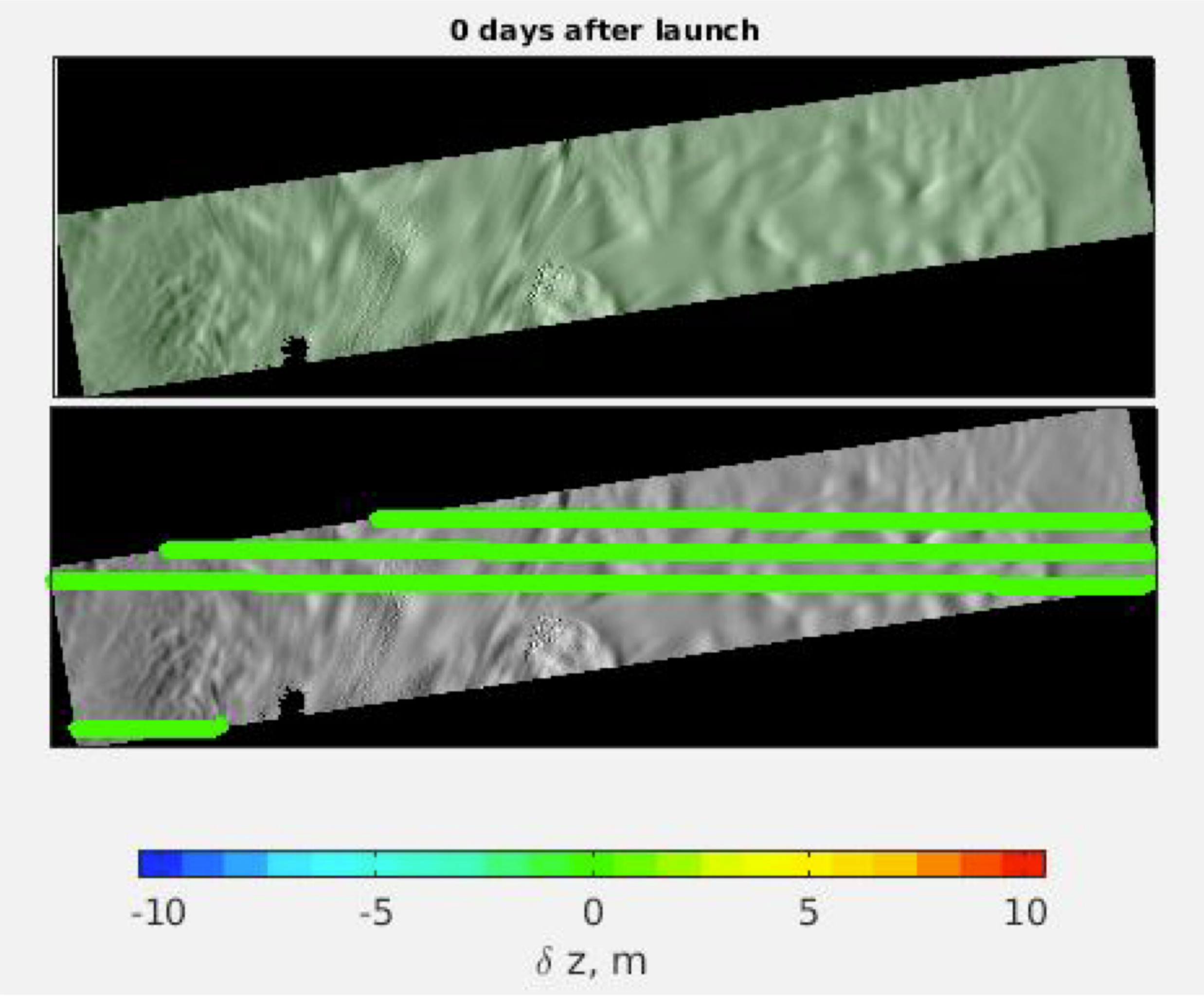
lat_1	**lon_1**	$time_{11}$	z_{11}	$time_{12}$	z_{12}	$time_{13}$	z_{13}	$time_{14}$	z_{14}	$time_{15}$	z_{15}		z_{1N}
lat_2	**lon_2**	$time_{21}$	z_{21}	$time_{22}$	z_{22}	$time_{23}$	z_{23}	$time_{14}$	z_{24}	$time_{25}$	z_{25}	…	z_{2N}
lat_3	**lon_3**	$time_{31}$	z_{31}	$time_{32}$	z_{32}	$time_{33}$	z_{33}	$time_{34}$	z_{34}	$time_{35}$	z_{35}		z_{3N}
						…							…
lat_M	**lon_M**	$time_{M1}$	z_{M1}	$time_{M2}$	z_{M2}	$time_{M3}$	z_{M3}	$time_{M4}$	z_{M4}	$time_{M5}$	z_{M5}	…	z_{3N}

ATL11 flow chart

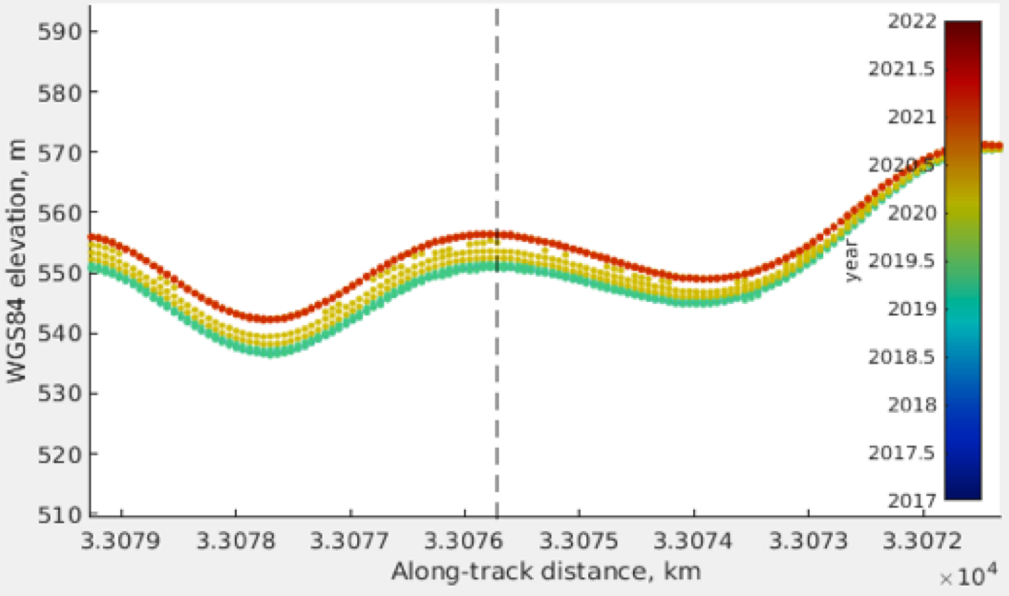


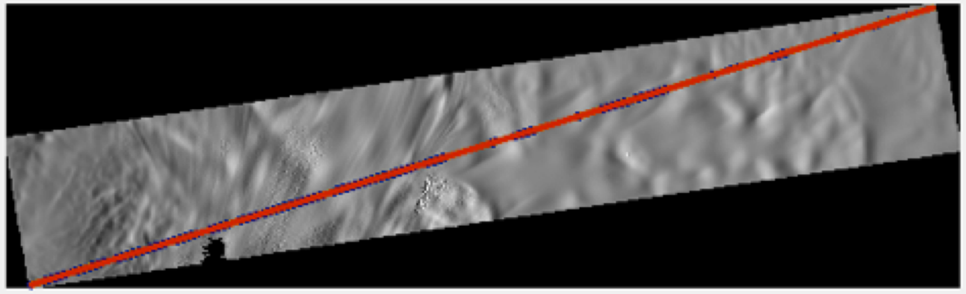
ATL11 simulated data

- Seed: PIG DEM plus a 30-km-wavelength sinusoid that grows in year 2
- Clouds simulated based on statistics of ICESat-1 cloud-thickness estimates

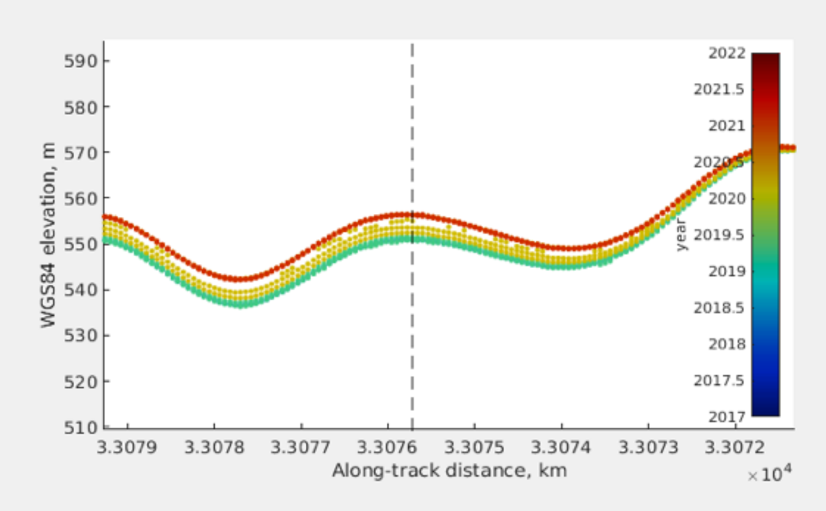


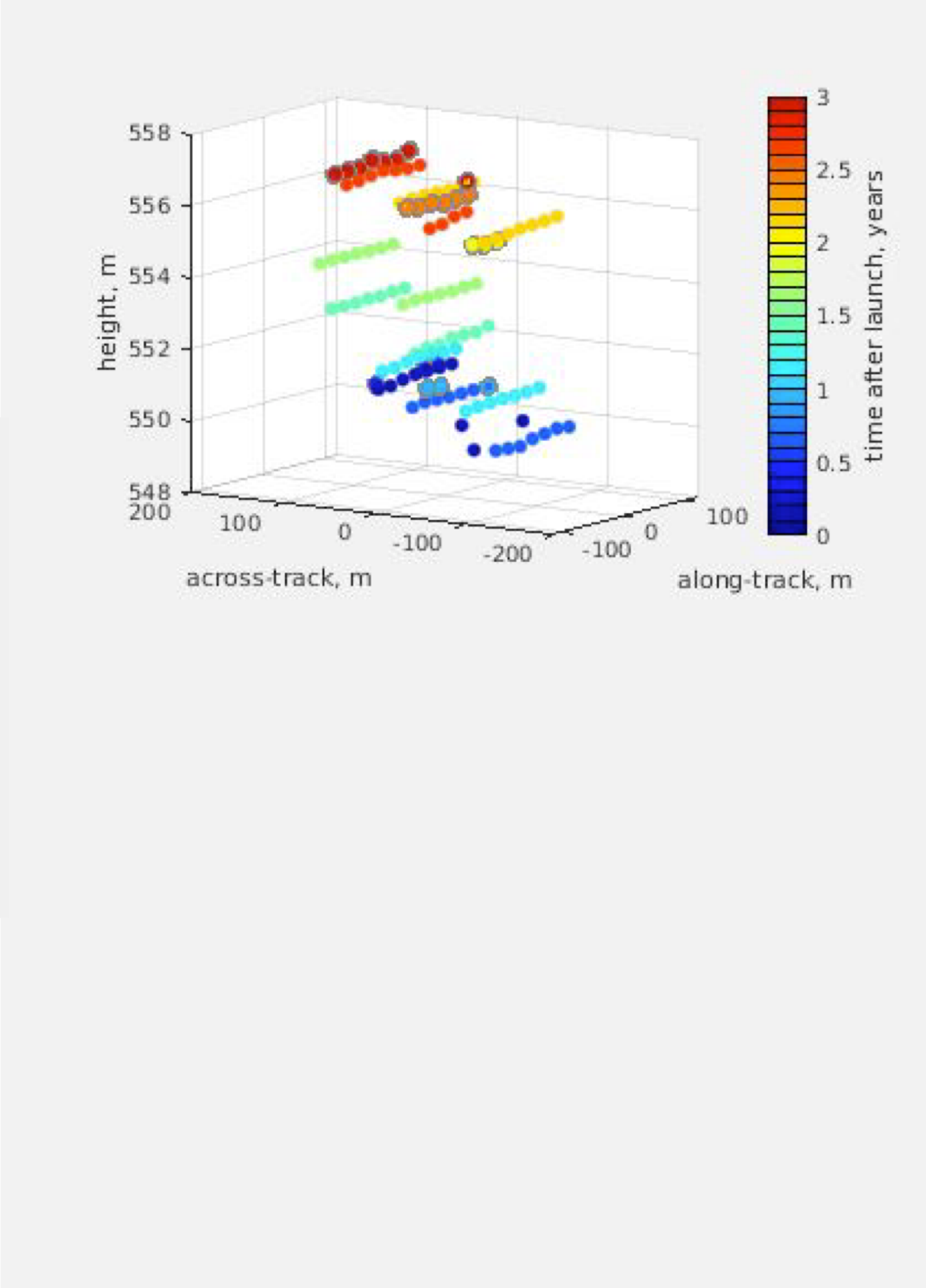
ATL11 correction schematic

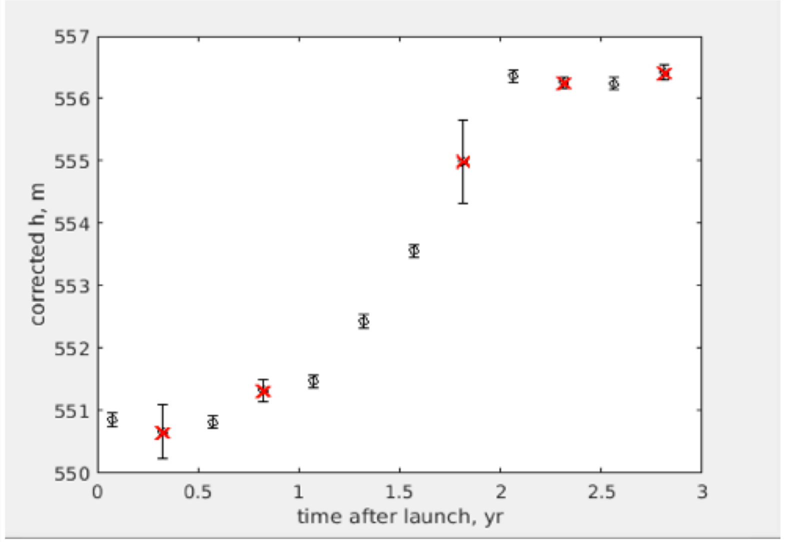




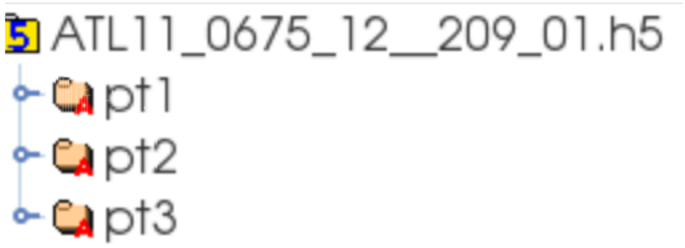
ATL11 correction schematic



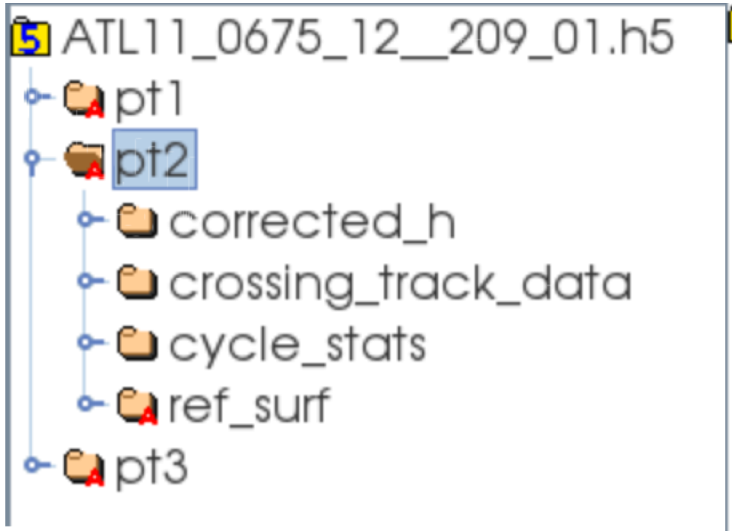




ATL11 structure:



One group per pair track



Corrected_h: latitude, longitude, h, time, and errors
Crossing-track data: data from crossing tracks
Cycle_stats: summary statistics of parameters for each cycle
Ref_surf: the location and shape of the reference surface

Corrected_h is intended to carry the most important parameters (lat, lon, time, and elevation for each cycle)

ATL14 and 15: Digital elevation models and elevation change

- ATL14 provides:
  - DEM, posted at 125 m
- ATL15 provides:
  - ICESat-1 – ICESat-2 elevation difference map, posted at 1 km
  - ATL14 elevation change surfaces, posted at 500 m / 3 mo.
- Least-squares-surface fitting algorithm combines ATL11 elevations to fill in gaps between tracks and missing repeats
- Both products will be regenerated each year, starting late 2019 / early 2020

$$z(t, x, y) = z_0(x,y) + \delta z(t, x, y)$$

ATL11
Height corrected for small-scale topography

ATL14
DEM

ATL15
Height-change maps

Status as of June, 2019

- We can’t generate along-track differences for ATL11 now (don’t have repeat data)
- Current ATL11 prototypes include:
  - Reference elevations defined from one reference cycle (cycle 1 or cycle 2)
  - Crossover elevations from both cycles
- For gridded elevation-change testing, I have experimented with ICESat-1-ICESat-2 differences

Elevation-differencing scheme for ICEsat-1-ICEsat-2 differences

- Given z(x, y, t, M), solve for:
    - $z_0(x,y)$
    - dz/dt(x, y)
    - B(M, t)
  - that minimizes:

$$R = \mathbf{r^T C_d^{-1} r} + (\mathbf{Fm})^T \mathbf{C_r^{-1}} (\mathbf{Fm})$$

- **r** : data-model misfit
- $\mathbf{C}_d$: Expected data errors
- **m**: DEM, elevation-change rate, data biases
- **F** : Complexity of the model
- $\mathbf{C}_r$: Expected complexity of the model

$$(\mathbf{F}\boldsymbol{m})^T \mathbf{C}_r (\mathbf{F}\boldsymbol{m})$$

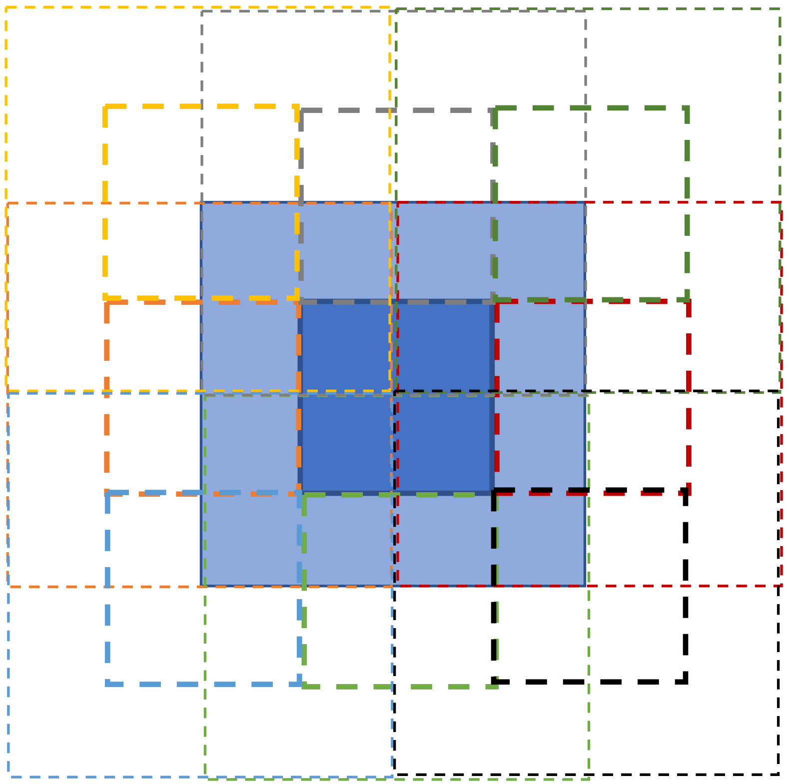
$$\approx \iint \frac{1}{\sigma_{xx}^2}\left[\left(\frac{\partial^2 z_0}{\partial x^2}\right)^2 + 2\left(\frac{\partial^2 z_0}{\partial x \partial y}\right)^2 + \left(\frac{\partial^2 z_0}{\partial y^2}\right)^2 + \frac{1}{L^2}\left[\left(\frac{\partial z_0}{\partial x^2}\right)^2 + \left(\frac{\partial z_0}{\partial y^2}\right)^2\right]\right.$$

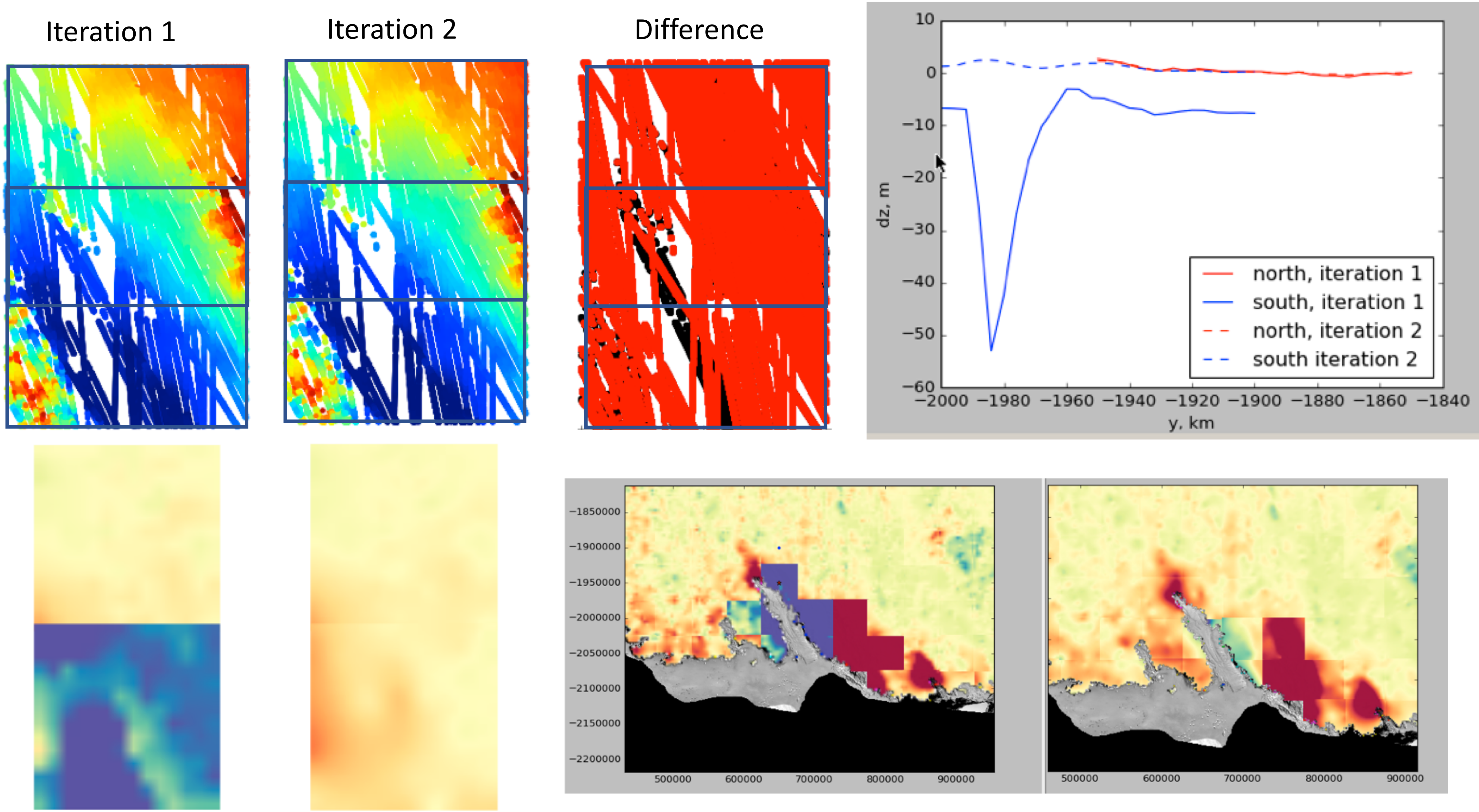
$$\left. + \left[\frac{1}{\sigma_{xxt}^2}\left[\left(\frac{\partial^2 \delta z_t}{\partial x^2}\right)^2 + 2\left(\frac{\partial^2 \delta z_t}{\partial x \partial y}\right)^2 + \left(\frac{\partial^2 \delta z_t}{\partial y^2}\right)^2 + \frac{1}{L^2}\left[\left(\frac{\partial \delta z_t}{\partial x}\right)^2 + \left(\frac{\partial \delta z_t}{\partial y}\right)^2\right]\right]\right]\right] dA$$

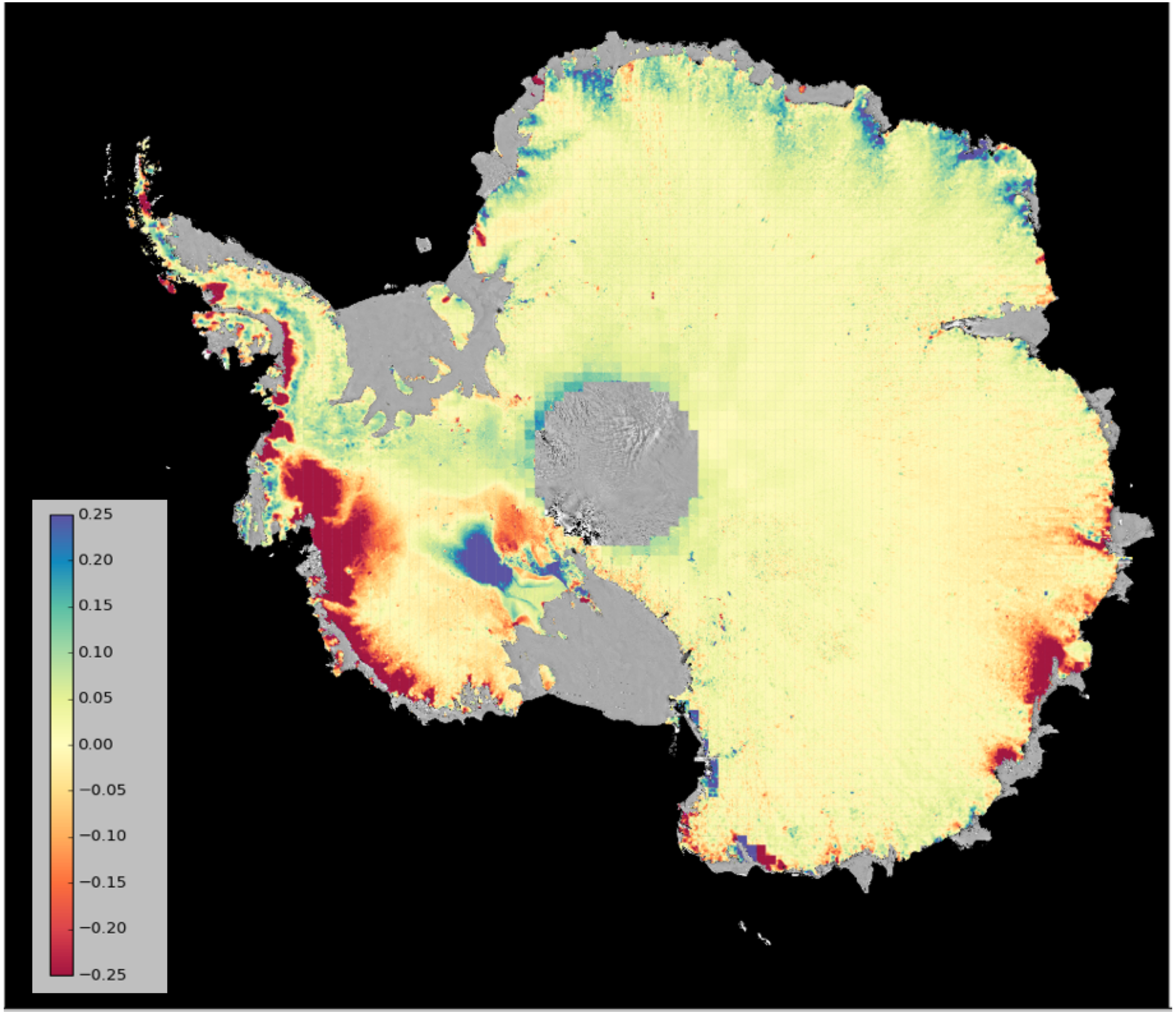
- Direct linear solutions are moderately difficult for 100x100 km areas:
  - Solve for z0 at 250 m
  - Solve for dz/dt at 2 km

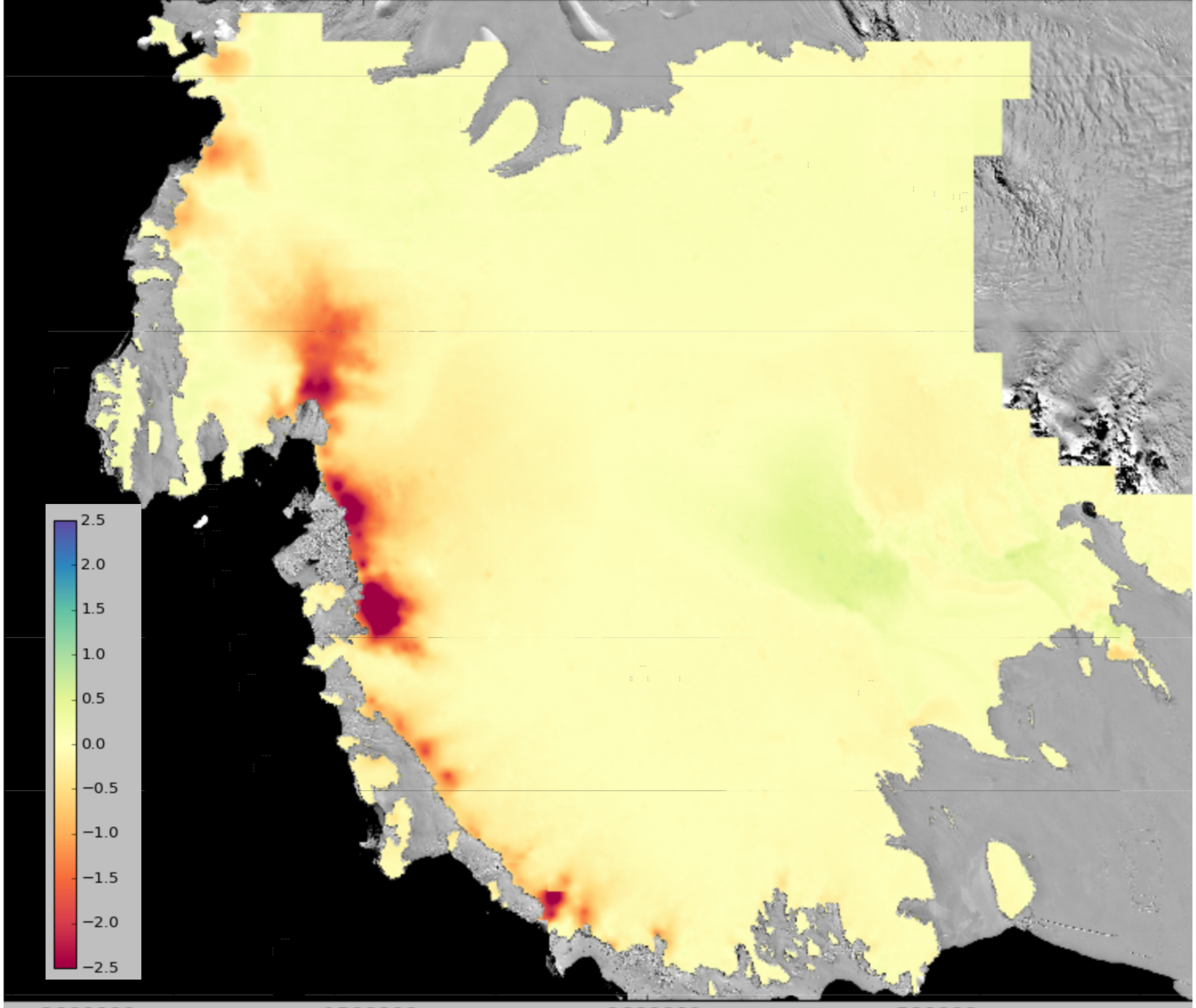
How does this work with IS1-IS2 data?

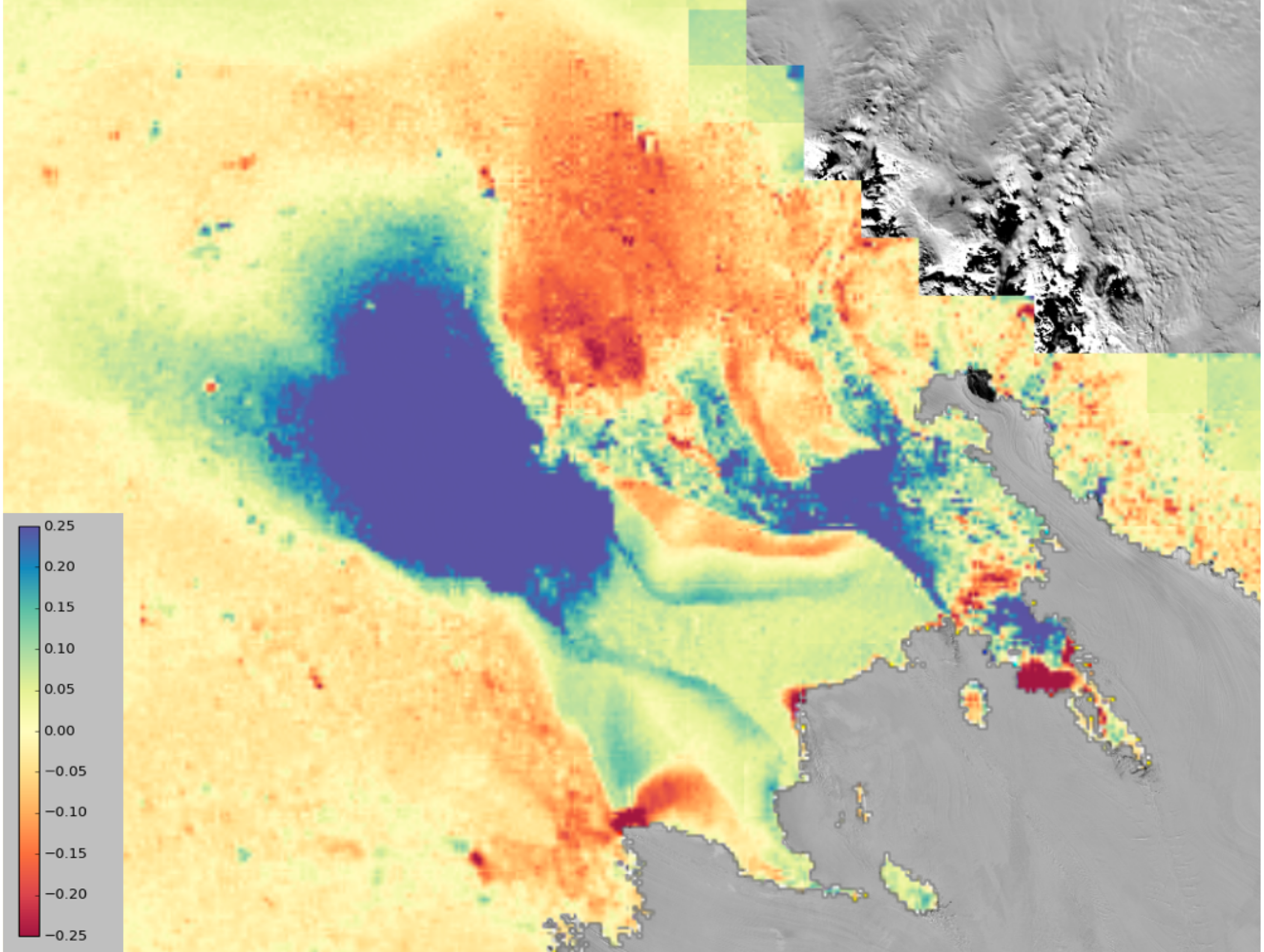
- Choose z_0 to be the surface height in 2020
- Operate on large (100-km x 100-km) tiles
    - Overlap tiles by 50%
- Use the REMA DEM to reject outliers from both datasets
    - tolerance = 3 max(1m, $\sigma_{mission}$)
- Iterate fitting and editing to reduce outliers
- After 6 iterations on each tile, form a consensus set of edited data between adjacent tiles, and run a final iteration to remove scene-to-scene boundaries




Iteration 1
Iteration 2
Difference
dz, m
y, km
10
0
−10
−20
−30
−40
−50
−60
−2000
−1980
−1960
−1940
−1920
−1900
−1880
−1860
−1840
north, iteration 1
south, iteration 1
north, iteration 2
south iteration 2
−1850000
−1900000
−1950000
−2000000
−2050000
−2100000
−2150000
−2200000
500000
600000
700000
800000
900000


0.25
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
−0.25


2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5


0.25
0.20
0.15
0.10
0.05
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−0.05
−0.10
−0.15
−0.20
−0.25